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13. ABSTRACT (<i>Maximum 200 Words</i>) In this research program the electromagnetic field radiated and received by a thin-wire probe or antenna mounted on the nose cone of a missile is determined. The probe is connected to a component within the missile by a coaxial waveguide. The probe may be driven by a generator having a specified voltage and frequency or, in the reception mode, it may be loaded by a specified terminal impedance. The analyses developed allow for the probe to be mounted on the nose cone proper or it may reside within a cavity in the nose cone with coupling taking place between the missile interior and exterior through a small circular aperture in the cavity wall at the nose cone tip. For enhanced accuracy, alternate methods for addressing this problem were developed. Experimental models were fabricated and measurements were made to confirm the theoretical data. The agreement between theoretical and experimental data is excellent.				
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INTRODUCTION

In this research program the electromagnetic field radiated and received by a thin-wire probe or antenna mounted on the nose cone of a missile is determined. In the radiation mode, the probe is fed from within the missile by a coaxial waveguide driven by a generator having a specified voltage and frequency, while in the reception mode the excitation is a known plane wave impinging upon the missile. The desired received signal is that across a load at the end of the coax connected to the probe. In addition these analyses have been extended to include the case that the probe resides within a cavity in the nose cone with coupling taking place between the missile interior and exterior through a small circular aperture in the cavity wall at the nose cone tip. An experimental model of this missile with a thin-wire probe mounted on the nose cone has been fabricated and measurements were made to confirm the theoretical data. A second model was constructed with the probe in an aperture-perforated cavity in the nose cone. Experimental data in both cases conformed well with computed data. In the former case with the probe on the nose cone, computed data was in excellent agreement with corresponding data determined experimentally at the White Sands Missile Range. The agreement between theoretical and experimental data is excellent.

Summary of Research

Due the complexity and variation from unit to unit of missiles in the arsenal, a mock missile with features replicating as many as feasible of those common to actual missiles was fabricated at the White Sands Missile Range. For the purpose of sensing field strengths, a thin-wire probe was mounted on the nose of the mock missile and attached via a coaxial cable to instrumentation inside the missile body. In the case of actual systems, the probe is connected to some component inside the missile body. The component would be either a source or generator in the radiation case, while in the reception mode it would be either a receiver or an amplifier. To represent the important influences of such internal components, the base of the wire probe is connected to the center conductor of a coaxial cable which extends into the body of the mock missile. The desired received signal is that across the load (impedance) at the end of the coax connected to the probe, while in the radiation case a known signal would be supplied at the end of the coax. The load impedance represents the input characteristics of the amplifier or receiver that, in the real missile case, would be connected to the coax.

Analyses of the mock missile have been performed at Clemson University and measurements have been made at the White Sands Missile Range. In these analyses, full account is taken of the coupling among the wire, the missile body proper, and the load impedance at the end of the coax. To assure accuracy, two sets of integral equations, founded upon different approaches, were developed and solved numerically. Identical results were obtained from these two approaches. There was remarkable agreement in theoretical results obtained at Clemson with data measured at White Sands. The soundness of the theory developed for the receiving and radiating characteristics of the wire probe on the mock missile is supported by the good agreement found in the

independent measurements performed on the same structure. Application of this theory will lead to a better understanding of the characteristics of actual missiles.

In a second phase of the project, the probe may be entirely within the nose-cone cavity or it may extend through a circular hole in the cone cap to the region outside the missile. In the former case, the signal reaches the probe through the cone-cap hole, while in the latter it can in addition couple to the exposed portion of the probe. Selected results have been verified experimentally on simplified laboratory models. Because the experiments performed allow only limited verification of the theoretical results, a second, independent integral equation method has been developed to analyze the structure. Data from the two methods are in very close agreement. The theoretical methods are sufficiently general to allow one to determine both the signal received at the load impedance due to an incident plane wave and the far-zone field radiated by the structure due to a signal generator placed excitation caused under the condition that the load impedance is replaced by a signal generator of known voltage and frequency.

The work on the penetration of a signal into the nose-cone cavity through very small apertures in its wall has led into a general investigation of general penetration through very small apertures into enclosures. The obvious approach that one would employ to compute the field that penetrates a surface through an aperture is to determine the surface current induced by the known source on the conducting surface and, subsequently, to compute the desired penetrated field from knowledge of the current. When the interior field is very small, which obtains in the case of the nose-cone cavity for common excitations, this "obvious" solution method alluded to above leads to results that can be in error by many orders of magnitude, *even though the induced surface current from which the penetrated field is determined is very very accurate*. To realize progress in small aperture penetration problems of this type, one must formulate solution methods that overcome these inaccuracy difficulties. Progress has been made in formulating alternate integral equation methods to solve this small aperture penetration problem and has led to journal papers in which this phenomenon is described and addressed.

Publications

Papers in Journals

1. Z. Qiu and C. M. Butler, "Analysis of a Wire in the Presence of an Open Body of Revolution," chapter 1, pp. 1-26, J. A. Kong (ed.), **Electromagnetic Waves: Progress in Electromagnetics Research 15**, EMW Publishing, Cambridge, MA, 1997.
2. C. L. Freeman and C. M. Butler, "Analysis of a Stripline in a Waveguide," **IEEE Transactions on Antennas & Propagation**, vol. 45, no. 11, pp. 1636-1644, Nov. 1997.
3. Q. Martin and C. M. Butler, "Corroboration of the Analysis of an Axially-Directed Antenna Exciting an Infinite Conducting Tube," **Journal of Electromagnetic Waves and Applications**, vol. 11, pp. 821-852, 1997.

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- 5 J. D. Shumpert and C. M. Butler, "Penetration through Slots in Conducting Cylinders: Part 2, TM Case," Analysis of a Strip in a Waveguide," **IEEE Trans. on Antennas and Propagation**, vol. 46, no. 11, pp. 1622-1628, Nov. 1998.

Paper in Conference Proceedings

1. C. M. Butler, "Integral equation techniques for penetration through small apertures," Proceedings, Joint 3rd International Conference on Electromagnetics in Aerospace Applications & 7th European Electromagnetic Structures Conference, pp. 219-225, Torino, Italy, Sept. 14-17, 1993.
2. J. D. Shumbert and C. M. Butler, "Penetration Through Small Apertures in Conducting Surfaces," Proc. of the International Symposium on Electromagnetic Theory (International Union of Radio Science), pp. 67-69, May 23-26, 1995, St. Petersburg, Russia.

Papers Presented at National/International Meetings

1. Z. Qiu and C. M. Butler, "Analysis of a wire in the presence of a hollow body of revolution with and aperture," 1993 IEEE AP-S International Symposium and URSI Radio Science Meeting, June 27-July 2, 1993, Ann Arbor, Michigan.
2. Z. Qiu and C. M. Butler, "Analysis of a wire probe mounted on the nose of a missile-like body of revolution," Digest, 1994 National Radio Science Meeting, Boulder, CO, January 1994.
3. Z. Qiu and C. M. Butler, "Analysis of bodies of revolution whose generating arcs possess junctions," URSI Digest, 1994 IEEE AP-S International Symposium and URSI Radio Science Meeting, Seattle, WA, June 19 - 24, 1994.
4. J. D. Shumpert and C. M. Butler, "Penetration through small apertures: some two dimensional examples," URSI Digest, 1994 IEEE AP-S International Symposium and URSI Radio Science Meeting, Seattle, WA, June 19 - 24, 1994.

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Graduate Students and Degrees Earned

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John D. Shumbert, MS, 1995 (worked on grant but was supported as NSF fellow)

Cathy L. Freeman	Ph. D, 1996 (worked on grant but was supported by DoD fellowship)
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